APPARATUS, METHOD OF AND SYSTEM FOR IMPROVING CAPACITY IN A COMMUNICATIONS NETWORK

The present invention relates to an apparatus, a method of and a system for improving capacity in a communications network of the type employing a first duplex technique and a second duplex technique, for example, a cellular communications system such as the Universal Mobile Telecommunication System (UMTS).

In order to achieve a two way communication (duplex) in a communications system, each direction of communication, i.e. from a mobile terminal to a base station (hereinafter referred to as the "uplink") and from the base station to the mobile terminal (hereinafter referred to as the "downlink"), must be separated in order to avoid inter-network interference, i.e. uplink transmissions jamming downlink transmissions, and vice versa. The separation can be achieved either in the frequency domain or the time domain.

Referring to Figure 1, a schematic diagram of bandwidth allocations for a UMTS is shown. The UMTS supports two duplex techniques, namely a Frequency Division Duplex (FDD) technique 100 and a Time Division Duplex (TDD) technique 102. For FDD, uplink communications between an FDD terminal 104 and an FDD base station 106 are via a first band of frequencies 108 and downlink communications between the FDD terminal 104 and the FDD base station 106 are via a second, different, band of frequencies 110. The two bands of frequencies 108, 110 used by the FDD technique are separated by a further frequency band, known as a duplex distance 112.

The TDD technique permits communication between a TDD terminal 114 and a TDD base station 116 in a single, unpaired, band of frequencies 118, but with time gaps, known as guard times 120, between periods of transmission and reception.

Figure 2 is a schematic diagram showing in more detailed the allocation of bandwidth shown in Figure 1. For symmetric traffic and a single switching point, the band of TDD frequencies 118 are sub-divided into 16 time slots $t_0, \ldots, t_{15}$, of which the first eight time slots $t_0, \ldots, t_7$ are dedicated to downlink traffic and the remaining eight time slots $t_8, \ldots, t_{15}$ are dedicated to uplink traffic.

In the UMTS, a plurality of TDD terminals $U_1, \ldots, U_n$ are capable of communicating with the TDD base station 116. A first predetermined number of terminals $U_1, \ldots, U_m$ are allocated the first time slot t_0 for downlink transmissions and the ninth time slot t_8 for uplink transmissions. Similarly, other predetermined numbers of terminals are allocated other time slots for uplink and downlink communications.

Taking the first TDD terminal U_1 of the first predetermined number of terminals $U_1, \ldots, U_m$, it will be appreciated that after being active during the first time slot t_0, the first TDD terminal is effectively idle 200 until the beginning of the ninth time slot t_8, i.e. no transmission or reception is taking place. The first TDD terminal U_1 is similarly inactive 202 after the ninth time slot t_8 until the beginning of the first slot t_0 of a succeeding frame. Therefore, it can be seen that each TDD terminal is only actively handling communications traffic for 1/8 of the duration of the frame. For CDMA, in contrast, communications traffic from FDD terminals occupy whole frames in the FDD bands of frequencies 108, 110 with instantaneously transmitting and receiving signals.

The above periods of inactivity are also experienced by the other TDD terminals $U_2, \ldots, U_n$; the second to m^{th} TDD terminal $U_2, \ldots, U_m$ are idle during the same periods of time as the first TDD terminal U_1, the remaining TDD terminals $U_{m+1}, \ldots, U_n$ being idle during different periods of time depending upon the time slots to which they are allocated.

With the increase of mobile data applications, for example, video, facsimile and file download from the Internet, the variable data rates and packet oriented services associated with these applications and the limited amount of radio resources allocated to a given communications system make demands on the air interface and cellular architecture associated with the system.

Consequently, the European Telecommunications Standards Institute (ETSI) UMTS standard permits the use of macro-, micro- and pico-cells, where the macro cells ensure overall coverage of a geographic area and the micro-, or even pico-cells, support areas of high telecommunications traffic, for example, hotels or airports. Additionally, as mentioned above, the UMTS will support two duplex techniques, namely the FDD technique and the TDD technique.

In the UMTS, due to the increase in the above described mobile data applications, large volumes of traffic are likely on the downlink. Consequently, due to the asymmetry caused by data traffic on the downlink, at least the uplink band of frequencies for the FDD technique is underused. Hence, unused radio resources allocated to the FDD technique represent a waste of channel capacity, especially when the TDD base station 116 is at maximum load. Handover between a TDD cell and an FDD cell may not be possible, because a TDD terminal may not be able to support the FDD technique, i.e. no dual mode capability, or the FDD cell and the TDD cell

may not be run by the same operator. Hence, it should be understood that the term “system” is intended to include more than one communications system comprising at least one respective duplexing technique, or a single system comprising at least two duplexing techniques.

It is therefore an object of the present invention to obviate, or at least mitigate the above-described problems caused by asymmetry of telecommunications traffic.

According to a first aspect of the present invention there is provided a communications system comprising a first duplexing technique to enable communication between a first base station and a first plurality of terminals, a second duplexing technique to enable communication between a second base station and a second plurality of terminals, and frequency allocation means arranged to allocate at least a portion of a frequency band allocated to the first duplexing technique to a terminal so as to enable the terminal to operate in accordance with the second duplexing technique within the frequency band allocated to the first duplexing technique.

According to a second aspect of the invention, there is provided a method of improving capacity in a communications system comprising a first duplexing technique to enable communication between a first base station and a first plurality of terminals, a second duplexing technique to enable communication between a second base station and a second plurality of terminals, the method comprising the steps of: allocating at least a portion of a frequency band allocated to the first duplexing technique to a terminal, and re-tuning the terminal so as to enable the terminal to operate in accordance with the second duplexing technique within the frequency band allocated to the first duplexing technique.

According to a third aspect of the invention, there is provided a terminal for use in a system comprising a first duplexing technique to enable communication between a first base station and a first plurality of terminals, a second duplexing technique to enable communication between a second base station and a second plurality of terminals, the terminal being arranged to receive an allocation of at least a portion of a frequency band allocated to the first duplexing technique and to operate in accordance with the second duplexing technique within the frequency band allocated to the first duplexing technique.

According to a fourth aspect of the invention, there is provided a base station for use in a system comprising a first duplexing technique to enable communication between another base station and a first plurality of terminals, the base station supporting a second duplexing technique for communications with a second plurality of terminals, and being arranged to allocate at least a portion of a frequency band allocated to the first duplexing technique to a terminal so as to enable the terminal to operate in accordance with the second duplexing technique within the frequency band allocated to the first duplexing technique.

It is thus possible to provide an apparatus, a method of and a system for improving capacity in a communications network in which the capacity of the second base station can be increased by approximately 40% by converting unused radio resources of the first base station when the load on the first base station is approximately 30%. Due to an increase in spectral efficiency, it is also possible to maintain a large guard time and hence increase the radius of the cell supported by the second base station. The increased spectral efficiency results in higher data throughput and is achieved without filter adjustments to FDD terminals and base stations. Since minimal hardware

and/or software modifications are necessary, the additional cost of implementing the present invention is minimal. Also, it is possible to assign different uplink and downlink capacities for a given terminal in the TDD cell, thereby obviating the need to change the switching point of the TDD cell. It is also asynchronous overlap with adjacent TDD cells is prevented.

Other, preferred, features and advantages are set forth in, and will become apparent from, the following description and accompanying dependent claims.

At least one embodiment of the invention will now be described, by way of example, with reference to the accompanying drawings, in which:

Figure 3 is a schematic diagram of a configuration of mobile terminals and have base stations constituting an example of the invention;

Figure 4 is a schematic diagram of bandwidth allocation for the example of Figure 3;

Figure 5 shows, in more detail, the use of bandwidth allocated to a TDD technique in Figure 4;

Figure 6 is a schematic diagram of bandwidth use constituting an embodiment of the invention;

Figure 7 is a graph illustrating improved system performance due to the embodiment of Figure 6.

Throughout the description, identical reference numerals will be used to identify like parts.

In a first embodiment of the invention, a UMTS 300 (Figure 3) comprises an FDD cell 302 supported by the FDD base station 106. A first TDD micro-cell 306, a second TDD micro-cell 308 and a third TDD micro-cell 310 are located substantially within the FDD cell 302 and are supported by a first TDD base station 116, a second TDD base station 314 and a third

TDD base station 316, respectively. Although the use of TDD micro-cells 306, 308, 310 is described herein, it should be noted that the invention is not limited to the use of micro-cells, and larger or smaller cells can be used, for example, macro- or pico-cells.

A plurality of FDD mobile terminals 318 are located within the FDD cell 302 and are in communication with the FDD base station 106 by means of a Radio Frequency (RF) interface. The plurality of FDD terminal 318 include the FDD terminal 104 described above.

The first TDD base station 116 is located within the first TDD cell 306 and is in communication with a plurality of TDD mobile terminals $U_1, \ldots, U_n$. Additionally, the first TDD base station 116 is synchronised with the FDD base station 106 so that data frames are aligned.

In operation (figure 4), the FDD uplink band of frequencies 108 and the FDD downlink band of frequencies 110 form a paired band of frequencies. The FDD terminal 104 transmits uplink communications traffic to the FDD base station 106 using the uplink band of frequencies 108. Similarly, the FDD terminal 104 receives transmissions from the FDD base station 106 via the downlink band of frequencies 110.

The TDD technique uses the single band of frequencies 118 described above which serves both uplink and downlink communications traffic between, for example, the first TDD mobile terminal U_1 and the first TDD base stations 116. In the case of the first TDD terminal U_1, uplink transmissions take place during the first time slot t_0 and downlink transmissions take place during the ninth time slot t_8.

A frequency allocation unit (FAU) 404 verifies that at least a portion 400, 402 of the FDD uplink band of frequencies 108 is not being used for the transmission of FDD traffic and, using a Dynamic Channel Allocation (DCA)

algorithm, determines which band of frequencies within the portion of the band of FDD uplink frequencies to use on the basis of mutual interference considerations. Subsequently, the first TDD terminal U_1 is instructed by the first TDD base station 116 to use one of the available uplink frequencies 400 allocated to the FDD technique for the transmission of uplink data, in time slots, according to the TDD technique. Similarly, if there are sufficient uplink frequencies available, i.e. capacity, one of the available FDD uplink frequencies 402 is used by the first TDD base station 116 to transmit downlink data in time slots according to the TDD technique.

Referring to Figure 5, the above-described embodiment can be seen in more detail. A Time Division-Code Division Multiple Access (TD-CDMA) scheme is used by the first TDD base station 116 in order to provide multiple access to the plurality of TDD terminals $U_1, \ldots, U_n$; the FDD base station 106 employs a Wideband CDMA (W-CDMA) multiple access scheme. The first time slot t_0 is allocated to a set of the TDD terminals $U_1, \ldots, U_m$ for uplink traffic. Similarly, the ninth time slot t_8 is allocated to the set of the TDD terminals $U_1, \ldots, U_m$ for downlink traffic. The uplink traffic and downlink traffic of the remaining mobile terminals $U_{m+1},\ldots, U_n$ is transmitted during the remaining time slots $t_1,\ldots,t_7$ and $t_9,\ldots,t_{15}$.

For simplicity of description and clarity, this embodiment of the invention will now be described with reference to the first TDD terminal U_1. The first TDD base station 116 is arranged to transmit CDMA encoded data to the first TDD terminal U_1 during the first timeslot t_0. After receiving the data transmitted by the first TDD base station 116 during the first time slot t_0, the FAU 404 monitors the band of FDD uplink frequencies 108 in order to determine whether or not there exists capacity in the band of FDD uplink frequencies 108, i.e. frequencies which are not being used by the FDD base

station 106. If frequencies are available in the band of FDD uplink frequencies 108, the first TDD base station 116 instructs the first TDD terminal U_1 to re-tune to a frequency which are known to be available in the band of FDD uplink frequencies 108. The first TDD base station 116 then continues to transmit time slots of CDMA encoded data to the first TDD terminal U_1 in the band of available frequencies.

Additionally, if sufficient capacity 500 is available within the band of FDD uplink frequencies 108 during the first time slot t_0, the available capacity 500 can be used by at least one of the TDD terminals $U_1, \ldots, U_m$ to transmit data whilst receiving data from the first TDD base station 116 (assuming the TDD terminal in question is capable of simultaneous transmission and reception). It should be appreciated that such dual functionality is not limited to the duration of the first time slot t_0 and that such functionality can be provided whenever capacity is available within the uplink band of frequencies 108.

At a predetermined period of time prior to the beginning of the ninth time slot t_8, the first TDD terminal U_1 re-tunes to an appropriate frequency within the band of TDD frequencies 118 in order to transmit CDMA encoded data to the first TDD base station 116 during the ninth time slot t_8.

Again, the dual functionality operation, i.e. simultaneous transmission and reception, can take place during the ninth time slot t_8, provided capacity is available within the uplink band of FDD frequencies 108.

Subsequent to the ninth time slot t_8, the FAU 404 again monitors the band of FDD uplink frequencies 108 in order to determine whether or not further available capacity exists within the band of FDD uplink frequencies 108. If capacity exists within the band of FDD uplink frequencies 108, the first TDD base station 116 instructs the first TDD terminal to re-tune to the

available frequency 402 within the FDD uplink frequencies in order to continue transmitting TD-CDMA encoded data to the first TDD base station 116, the first TDD terminal U_1 re-tuning to an appropriate frequency in the TDD band of frequencies 118 at a predetermined period of time prior to the commencement of the first time slot t_0 in a subsequent frame.

It should be appreciated that instead of transmitting data to the first TDD base station 116, the available capacity in the band of FDD uplink frequencies 108 can be used by the first TDD base station 116 to transmit further data to the first TDD terminal U_1. Similarly, instead of transmitting data to the first TDD terminal U_1, the available capacity in the band of FDD uplink frequencies 108 can be used by the first TDD base station 116 to receive further data from the first TDD terminal U_1.

In a second embodiment of the invention, instead of using the available capacity within the band of FDD uplink frequencies 108 for the transmission of additional data by existing TDD terminals $U_1, \ldots, U_n$, the additional capacity can be used to permit a new TDD terminals U_{n+1} to communicate with the first TDD base station 116. It should be appreciated that more than one new TDD terminal can be supported by the system provided the band of uplink frequencies 108 has sufficient capacity to support traffic from or to the more than one new TDD terminal.

The use of the band of FDD uplink frequencies 108 by the new TDD terminal U_{n+1} or the use by existing TDD terminals $U_1, \ldots, U_n$ of the band of FDD uplink frequencies 108 can cause some additional interference within the band of FDD uplink frequencies. However, if the first TDD micro-cell 306 is separated from the FDD base station by walls of a building or by a distance r_b, the additional interference will not greatly affect any FDD link. Since there are two possible bands of frequencies for placing the additional

TDD link, i.e. the uplink or the downlink band of FDD frequencies 108, 110, the DCA algorithm can be employed in order to select the band of frequencies which will result in the least mutual interference. In most cases, this will be the band of FDD uplink frequencies 108.

In a third embodiment of the invention, a CDMA-TDD scheme is employed within the TDD band of the frequencies 118 (Figure 6). The CDMA-TDD scheme comprises a first time slot ts_0 and a second time slot ts_1 separated by a guard time t_g. The guard time t_g is provided in order to avoid collisions between transmitting and receiving time slots ts_0, ts_1, because there is always a delay caused by signal propagation and signal processing; these delays are summarised and referred to as a round trip delay t_{rd}. A terminal U_m located at the boundary of the first TDD micro-cell 306 suffers from the greatest round trip delay t_{rd}. In contrast, the first TDD terminal U_1 is assumed to be closer to the first TDD base station 116, resulting in less round tip delay t_{rd}.

During operation, the plurality of TDD terminals $U_1, ..., U_n$ transmit CDMA encoded data for the duration of the first time slot ts_0. During the first time slot ts_0, the FAU 404 monitors the band of FDD uplink frequencies 108 in order to determine whether or not capacity exists within the band of FDD uplink frequencies 108. If capacity exists amongst the band of FDD uplink frequencies 108, the first TDD base station 116 permits the new TDD terminal U_{n+1} to communicate with the first TDD base station 116. After the first time slot ts_0 has expired, and if capacity still exists amongst the band of FDD uplink frequencies 108, the first TDD base station 116 either permits the new TDD terminal U_{n+1} to continue transmitting or receiving data to/from the first TDD base station 116. Alternatively, or additionally, the first TDD base station 116 permits one of the existing plurality of TDD terminals U_1,

..., U_n, for example, the first TDD terminal U_1 to re-tune to one of the available frequencies within the band of FDD uplink frequencies 108, and to continue receiving CDMA encoded data from the first TDD base station 116. If the first TDD terminal U_1or the new terminal U_{n+1} is to use available frequencies in the band of uplink frequencies 108, it is preferable, but not essential, for the first TDD terminal U_1 or the new terminal U_{n+1} to transmit or receive packet oriented data. The transmission or reception of packet oriented data is preferable because the available capacity in the band of FDD frequencies 108 cannot be guaranteed at any time and so should be used for very low priority traffic which does not require a guaranteed response time.

At a predetermined period of time prior to the beginning of the second time slot ts_1, the first TDD terminal U_1 re-tunes to the band of TDD frequencies 118 or in the case of the new user U_{n+1}, the new user U_{n+1} can enter a transmit mode in order to transmit data to the first TDD base station 116.

Although the above embodiments illustrate the use of available frequencies within the band of FDD uplink frequencies 108, the FAU 404 can be arranged to determine whether capacity exists within the band of FDD downlink frequencies 110 for use by the first TDD base station 116 and the plurality of TDD terminals affiliated thereto. Consequently, the first TDD base station 116 then either instructs an existing TDD terminal to re-tune to the available frequency or instructs the new TDD terminal U_{n+1} to use the available frequency 400, 402.

Referring to Figure 7, in simulations where r_b is between 300m and 500m and the TDD base station 116 is placed within this area and the plurality of TDD terminals U_1, ..., U_n are equally distributed, there is additional capacity within the band of FDD uplink frequencies when there are

less than 10 FDD terminals active at the same time. These values are calculated on the basis of outage, where the interference becomes too high so that a base station or a terminal loses its connections and a call or even all calls are dropped, being 5%.

If, for example, the first TDD base station 116 is located at a radius of $r_b = 500m$ and assuming 5 active FDD terminals and an identical data rate to the FDD base station 106, capacity exists for an additional 15 TDD terminals within the first TDD cell 306. Alternatively, this additional capacity can be shared between existing TDD terminals $U_1, \ldots, U_n$, or used for a single existing user, for example, by increasing the data rate of the first TDD terminals U_1 by a factor of 15. Optimum results have been obtained in the above simulations when the TDD base station 116 is located between approximately 200 and 500m from the FDD base station 106.

The above results of simulations are based upon a spatially uniform distribution of FDD terminals and imply an average over infinite user distributions. However, it should be appreciated that in any environment there is likely to be constellations of terminals which affect the available capacity within the band of FDD frequencies 108, 110. In particular, certain distributions of FDD terminals 318 will result in an increase in capacity, or a maintenance in capacity for an additional number of terminals, whereas other distributions will result in a decrease in capacity.

It should be appreciated that although the above embodiments have been described in relation to particular multiple access schemes used in conjunction with the duplexing techniques any multiple access scheme may be employed, for example, TDMA, CDMA, Space Division Multiple Access (SDMA), or Frequency Division Multiple Access (FDMA).

Although the above embodiments have been described in the context of the second duplexing technique using a portion of the frequency band of the first duplexing technique, it should be appreciated that the converse arrangement is also possible, i.e. the first duplexing technique using at least a portion of the band of frequencies of the second duplexing technique, such as at least one FDD terminal 318 using a portion of the unpaired TDD band of frequencies 118.